Hydrology and Effects of Conservation Structures, Willow Creek Basin, Valley County, Montana, 1954–68

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1532–G

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By DONALD G. FRICKEL

HYDROLOGIC EFFECTS OF LAND USE

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1532–G

A presentation of hydrologic data and a study of the effectiveness of conservation structures in a 538-square-mile area in northeastern Montana

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CONTENTS

	Page
Abstract	G1
Introduction and purpose of report	1
Location and topography	2
Climate	4
Geology, soils, and vegetation	6
Frequency analysis	7
Precipitation	8
Runoff	11
Analysis of data	12
Erosion and sediment yield	22
Relation to distribution of vegetation	24
Method of estimating sediment yield	28
Conservation structures	29
Effects on runoff	29
Effects on sediment yield	31
Summary	33
References cited	34

ILLUSTRATIONS

	Page
FIGURE 1. Index map showing location of the Willow Creek study area, Montana	G3
2. Map of Willow Creek basin, showing study basins and distribution of sedimentation rates	4
3. Graph showing average monthly precipitation	7
4–5. Precipitation-frequency curves showing:	
4. Total annual precipitation	9
5. Maximum storm precipitation	10
6. Graph showing the annual precipitation for the period of record	11
7–9. Flood-frequency curves showing:	
7. Runoff rates	13
8. Variation of mean annual rate with basin area	14
9. Runoff volume	15
10. Graph showing relative amounts of particles detached from soils	25
11–12. Photographs showing:	
11. Typical sagebrush area	26
12. Hardpan terrace with "slick" and "semislick" areas	27
13. Cross section of Willow Creek at the gaging station, showing significant changes during the period	29
14. Graph showing relation between monthly sediment load and monthly runoff	32

TABLES

		Page
TABLE	1. Reservoir capacity in Willow Creek basin	G2
	2. Runoff measured in Northwest Burnett reservoir	16
	3. Runoff measured in Cactus Flat reservoir	19
	4. Runoff measured in Sheepshed reservoir	20
	5. Sediment yield during periods between surveys	23
	6. Annual suspended-sediment load and stream discharge measured at Willow Creek gaging station	24
	7. Distribution of major vegetation types in the study basins and measured yields	26
	8. Computed sediment yields associated with major vegetation types	28

HYDROLOGY AND EFFECTS OF CONSERVATION STRUCTURES, WILLOW CREEK BASIN, VALLEY COUNTY, MONTANA, 1954-68

By Donald G. Frickel

ABSTRACT

This report presents the results of hydrologic observations in Willow Creek basin in northeastern Montana for the period 1954–68. Frequency curves for runoff and precipitation are provided.

The average annual precipitation for the 14-year period 1954–67 was about 0.5-inch less than the 30-year average; also, the average for the first half of the period was 3.4 inches less than that for the second half. Runoff records show that about two-thirds of the seasonal (April through October) runoff occurs in two events. The average seasonal runoff volume measured at Northwest Burnett, Cactus Flat, and Sheepshed reservoirs was 93.9, 96.5, and 37.5 acre-feet per square mile, respectively, for the 10-year period 1958–67. Sediment yields from Northwest Burnett, Cactus Flat, Sheepshed, and Triple Crossing basins varied from 0.1 to about 2.0 acre-feet per square mile. The apparent relation between the sediment yield of an area and the occurrence of major vegetation types in that area was used as a basis for projecting the measured rates to other areas in the basin for estimating sediment yields.

During the study period numerous reservoirs and waterspreaders were constructed in the basin. This upstream regulation of flow has caused a decrease in both the channel dimensions and the suspended-sediment load at the gaging station near the mouth of the basin. The peak stream discharge recorded at the gaging station is estimated to be about 45 percent less than it would have been had no reservoirs or waterspreaders been in the basin. The annual runoff volume recorded at the gaging station is estimated to be 18 percent less than it would be if the basin were totally uncontrolled. The capacity of the reservoir system is being reduced at an estimated rate of 1.6 percent, owing to sedimentation.

INTRODUCTION AND PURPOSE OF REPORT

In the early 1950's the Bureau of Land Management initiated an extensive conservation program in the Willow Creek basin, near Glasgow, Valley County, Mont. (fig. 1). The objective of this program was to control runoff and sediment yield and to increase forage production with conservation structures. By the end of

1967, reservoirs providing storage capacity of about 48,000 acre-feet (table 1) had been constructed. The reservoirs detain runoff and sediment from approximately 75 percent of Willow Creek basin. Waterspreading systems supply some additional storage capacity and also provide irrigation to about 4,500 acres of hay and pastureland. Contour furrowing has been applied to some parts of the basin as an additional conservation treatment. Early in the program the U.S. Geological Survey began collecting data to supply the hydrologic information needed to design the conservation structures and to evaluate the effectiveness of the conservation measures. Initial work involved monitoring a severe headcut in the main channel of Willow Creek. These observations led to the construction of a dam to control the headcut. Observations of sediment yield were begun in three reservoirs in 1952.

TABLE 1.—*Reservoir capacity in Willow Creek basin*

Year	Cumulative number of reservoirs	Cumulative capacity[1] (acre-ft)	Year	Cumulative number of reservoirs	Cumulative capacity[1] (acre-ft)
1941–53	34	1,641	1961	108	30,322
1954	57	7,163	1962	116	32,058
1955	57	7,163	1963	119	32,077
1956	68	11,419	1964	148	40,679
1957	80	18,679	1965	161	46,366
1958	92	19,755	1966	176	47,926
1959	92	19,755	1967	190	47,963
1960	106	23,350			

[1]This is constructed capacity. Usable capacity may be considerably less.

Runoff and sediment measurements were begun at Northwest Burnett reservoir (hereafter referred to as Burnett reservoir) in 1954 (fig. 2). As additional reservoirs were built, more stations were established to measure runoff and sediment yields from areas representing a variety of the terrain and vegetative conditions existing in the basin. This report is a compilation of the data collected through June of 1968 and presents an analysis of the effectiveness of the conservation measures in the basin.

Information on conservation structures and aerial photographs were provided by the Malta district of the Bureau of Land Management. The assistance given by the personnel of the Fort Peck Field Headquarters, Montana district, U.S. Geological Survey, who served as observers, is gratefully acknowledged.

LOCATION AND TOPOGRAPHY

Willow Creek drains an area of about 547 square miles (538 square miles at gaging station) in northeastern Montana. The creek is on the north side of Fort Peck Reservoir and flows northeastward to join the Milk River about 3 miles southeast of Glasgow, in Valley County. It has two major tributaries—Lone Tree Creek and Beaver Creek (fig. 2) —which drain about

45 percent of the basin. The basin is used for grazing, forage production, wildlife habitat, and some farming.

Streams in the basin are naturally ephemeral; however, some may now have long periods of low flow as the result of outflow from the many detention dams in the basin. Stream channels are deeply entrenched and are actively eroding, thus contributing much sediment directly into the main channel of Willow Creek. This is especially true along the lower reaches. The average gradient of Willow Creek from the confluence of its South and North Forks to the Milk River is 4.5 feet per mile. This is a relatively flat gradient for a stream in the Western United States.

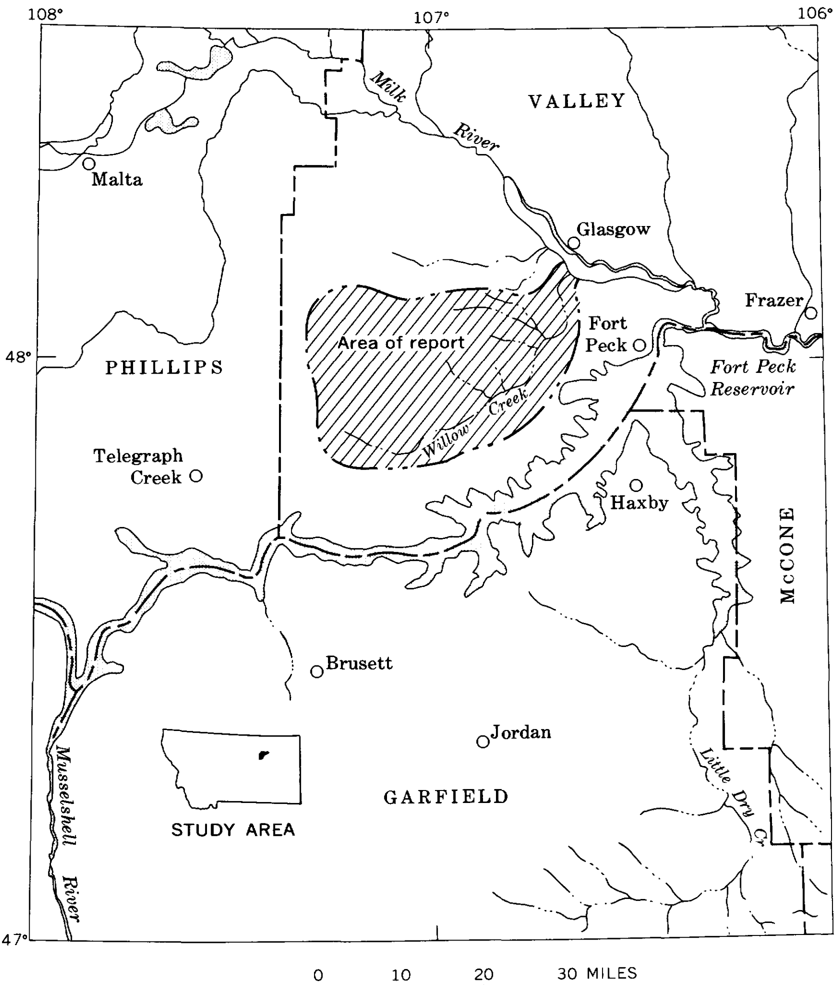


FIGURE 1. — Index map showing location of the Willow Creek study area, Montana.

The basin has low to moderate relief, with elevations ranging from 2,000 feet to about 2,800 feet above sea level. The topography is characterized by rolling uplands interspersed with a well-defined drainage system of relatively flat floored valleys.

CLIMATE

The climate in the Willow Creek basin is of the continental type. The mean annual precipitation at Glasgow, about 6 miles

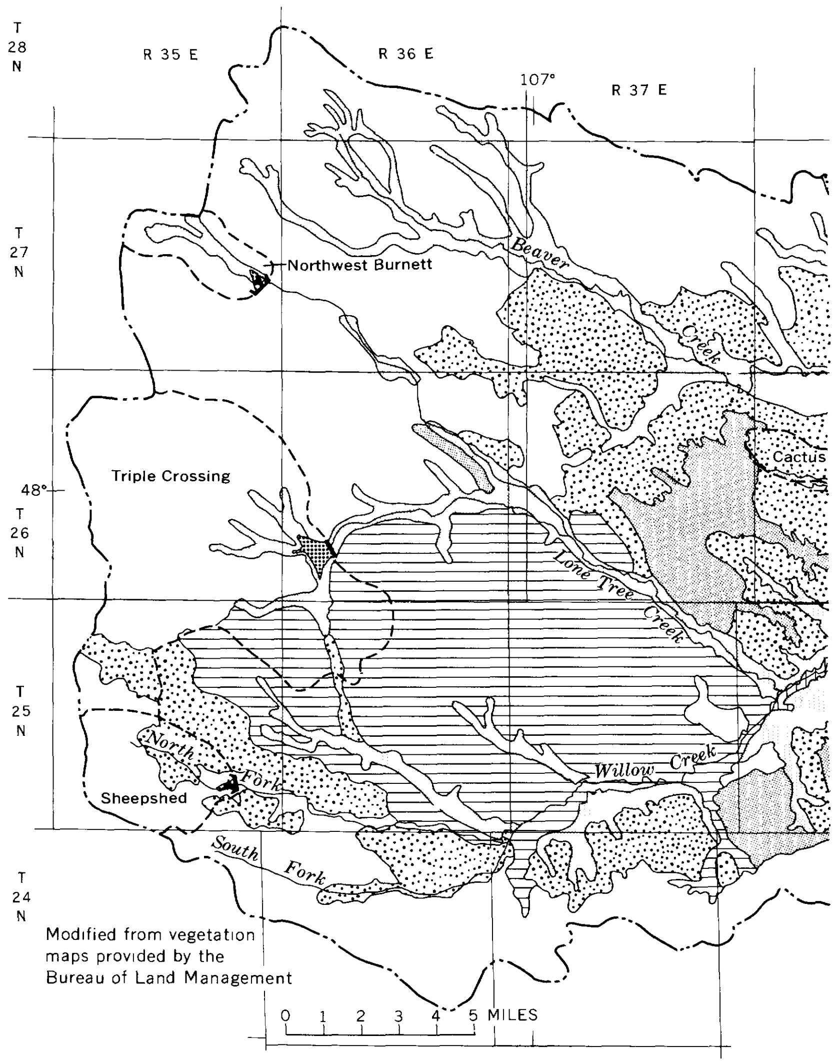
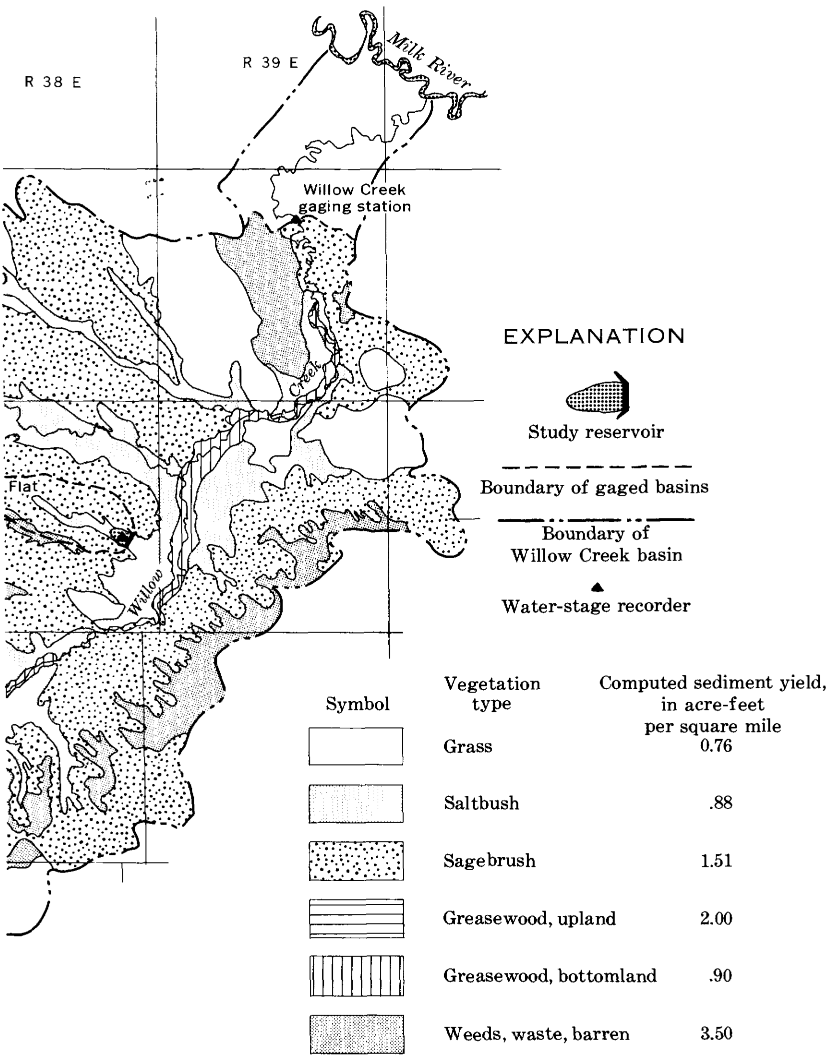


FIGURE 2. — Study basins, main drainage channels, and areal

north of the Willow Creek gaging station, is 12.67 inches, based on 54 years of National Weather Service (U.S. Weather Bur.) records. Usually, most of the precipitation in any given year is received during the summer, with the highest amount occurring in June and the next highest amounts in May and in August (fig. 3). The storms during May and June commonly last for several days and contribute approximately 40 percent of the total annual precipitation. The late summer storms generally occur as



distribution of computed sedimentation rates in Willow Creek basin.

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short-duration thunderstorms. In the summer months (April through September) precipitation in the basin averages 9.69 inches, whereas precipitation during the winter months (October through March) averages only 2.98 inches. Storm precipitation during the winter months occurs mostly as snow.

Northeast Montana experiences a wide range in temperatures annually. The average maximum daily temperature for July at Glasgow is 87.6°F, and the average minimum daily temperature for January is −1.9°F. The highest temperature ever recorded at Glasgow, 113°F, occurred in July of 1900; the record low, −59°F, occurred in February of 1936. Mean annual temperature is 42.3°F and the mean for the months of April through September is 60.6°F. The temperature span between maximum and minimum daily temperatures averages about 23°F.

GEOLOGY, SOILS, AND VEGETATION

Willow Creek basin is underlain by the Bearpaw Shale of Late Cretaceous age. The Bearpaw, a black marine shale high in sodium content, is easily eroded. Along the rim of the basin, the Bearpaw is overlain by the relatively resistant sandstone of the Fox Hills and Hell Creek Formations. Glacial drift deposits are scattered throughout the basin, but only in thin layers of small areal extent. A detailed description of rock units occurring in the Willow Creek area is given by Jensen and Varnes (1964).

Soils in the basin reflect the characteristics of their parent formations. The valley alluvium, derived primarily from the Bearpaw Shale, is very fine grained and relatively impermeable. A significant feature of the nonflooded alluvial soils is the development of hardpan "slicks" and "semislicks." These areas, described by Branson, Miller, and McQueen (1962), produce very little forage, but they apparently have a significant effect on sediment yield and runoff. Soils on the valley side slopes are composed basically of weathered shale in which various amounts of coarser material are evident in some areas. The soils near the basin divide, derived from the Fox Hills and Hell Creek Formations, are sandier and produce more forage than the other soils in the basin.

Vegetation in the Willow Creek basin is typical of that in the High Plains. Principal plants are nuttall saltbush (*Atriplex nuttallii*), big sagebrush (*Artemisia tridentata*), sandberg bluegrass (*Poa secunda*), blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), and black greasewood (*Sarcobatus vermiculatus*).

The distribution of plants generally varies with the changes in soil type. Greasewood and western wheatgrass occur on the present flood plains, and nuttall saltbush is the dominant species on the alluvial terraces that were flooded before the present valley trenching began. Big sagebrush, blue grama, and sandberg bluegrass are the main species found on the valley side slopes and ridge tops. Big sagebrush is dominant on the shale soils, whereas the grasses are dominant on the sandier soils along the rim of the basin.

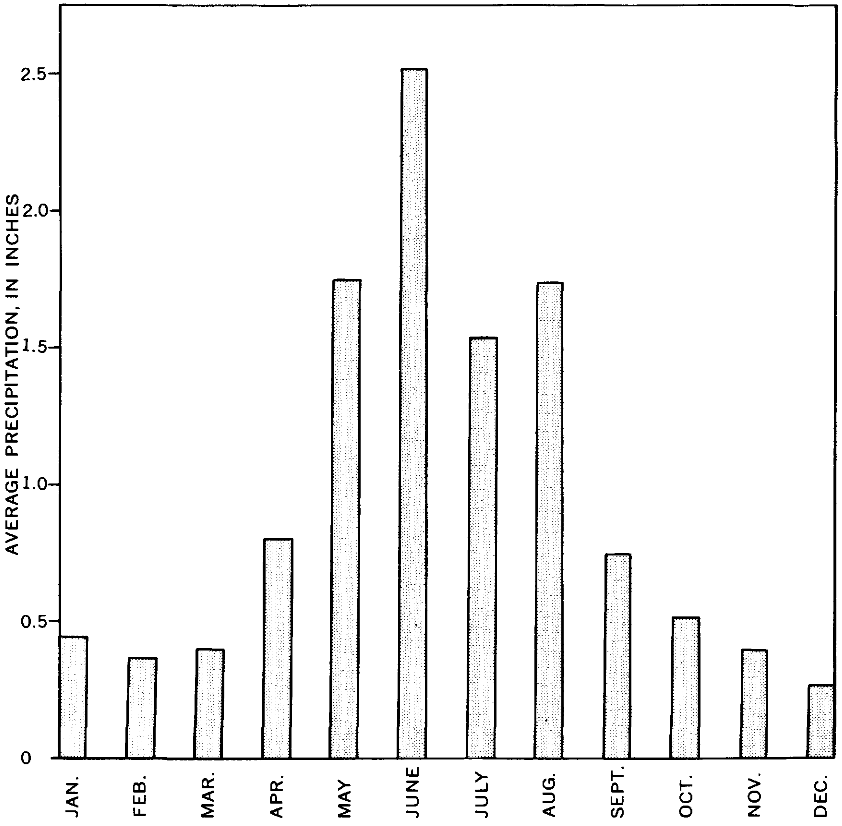

FIGURE 3. — Average monthly precipitation at Glasgow, Mont., 1954–67.

FREQUENCY ANALYSIS

Knowledge of the magnitude and frequency of hydrologic events is essential to sound, economic design of conservation structures. Frequency curves are used to relate the magnitude of a recorded hydrologic event to the probable frequency of recurrence of like events. A single short-term station record may contain a large "chance" variation from the "correct" value. This variation can be reduced by developing a regionalized or composite frequency relation from a number of station records within a hydrologically homogeneous region. Benson (1960) showed that by using the composite relation of five or more 10-year records, the 10-year event could be predicted within 5.7 percent of the correct value; however, to obtain similar accuracy by using the relation of an individual station, a 90-year record was required.

A regional frequency curve shows the relationship of a dimensionless quantity, called the "event" ratio (flood ratio, precipitation ratio), to its recurrence interval. The ratios are determined by dividing the event of a given frequency by an "index" event, usually the mean annual event, using values obtained from the frequency curves of individual stations. Ratios are computed at selected recurrence intervals for each station to be included. The median ratio values are plotted against their respective recurrence intervals to define the regional frequency curve.

In order to use the frequency curve, a means of estimating the index event at any point in this region is necessary. This is usually accomplished by relating the index event to the drainage-basin area or to some other basin characteristic(s). By use of this relation with the regional frequency curve, a frequency curve can be defined for any location within the region. Dalrymple (1960) described the procedure for regionalizing station data in detail.

Regionalized precipitation-frequency and runoff-frequency curves were defined for the Willow Creek area. The common time base used for the annual precipitation-frequency curve was 54 years. For reasons explained later, the time base for the 1-day and 3-day precipitation curves was reduced to 44 years. The runoff volume and discharge curves have a time base of 14 years.

PRECIPITATION

Three regionalized precipitation-frequency curves were developed for use in the Willow Creek area. These curves (figs. 4, 5) relate the annual precipitation and the maximum 1-day and maximum 3-day precipitation to the recurrence interval. They were developed from data published in the reports "Climatological Data" of the National Weather Service (U.S. Weather Bur.) for stations in the Willow Creek area. The 1-day, 3-day, and 1-year time intervals were selected on the basis of available data and usefulness in design and management planning. Generally, 3 consecutive days is the maximum length of major storms in the area, although a small amount of the total storm precipitation may fall on the fourth and fifth days.

Records from weather stations at Glasgow, Frazer, Fort Peck, Haxby, Jordan, Brusett, Telegraph Creek, and Malta were selected on the basis of location and length. Willow Creek basin is within the area bounded by these stations (fig. 1). Records from the above weather stations are for periods varying in length from 18 to 54 years, through 1968. Only two of the records were for periods of less than 30 years, and one of those was a 28-year record. All met the test for hydrologic homogeneity.

The double-mass curve technique described by Searcy and Hardison (1960) was applied to the annual precipitation amounts. The double-mass curves for the Glasgow, Frazer, and Jordan stations had significant slope breaks, and the annual precipitation amounts for these stations were adjusted accordingly. Because there is no method for making adjustments on individual storm amounts, these stations were excluded from the analyses of maximum 1-day and 3-day storms. As a result of this exclusion, the common time base represented by the frequency curves was shortened to 44 years.

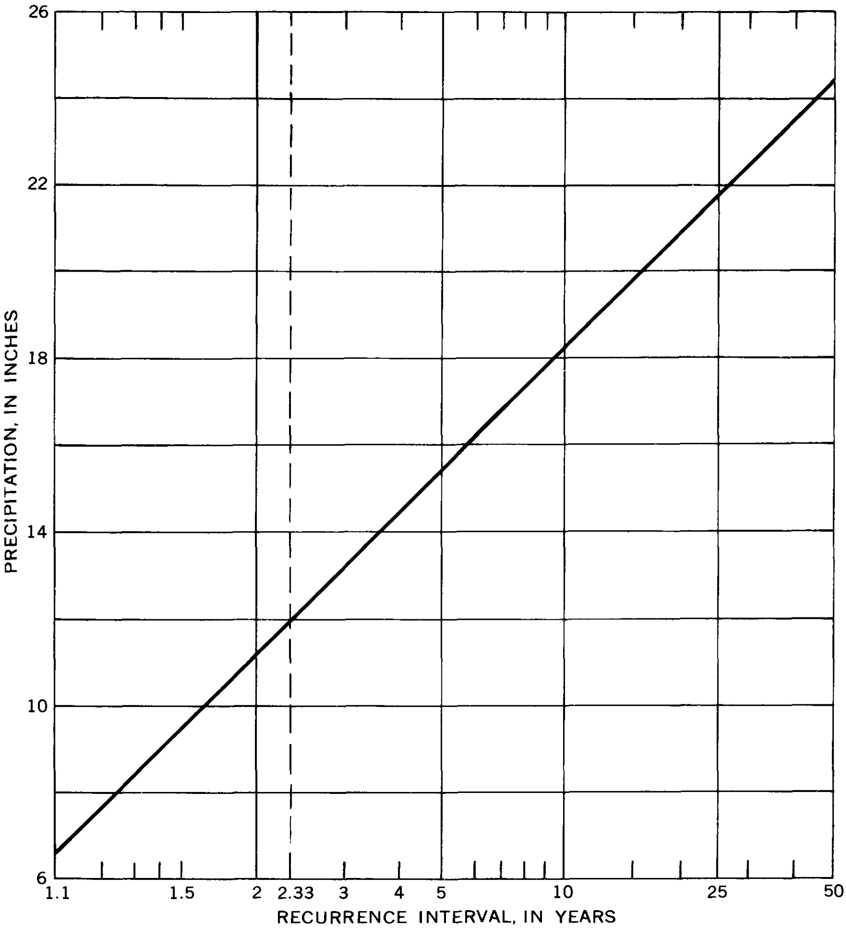

FIGURE 4. — Annual precipitation-frequency curve for the Willow Creek area.

The ordinate quantities of the precipitation-frequency curves (figs. 4, 5) are not dimensionless. Because a satisfactory relationship for estimating the index-precipitation event at any site was not found, a single value was applied to the whole region, thus permitting actual precipitation quantities to be shown on the frequency curves. The value used was the median of the station mean annual precipitation amounts.

The annual precipitation in the Willow Creek area varied from 7.01 inches to 17.37 inches in the 14-year period during which runoff records were collected (fig. 6). The annual amounts are the averages of the amounts recorded at eight National Weather Service (U.S. Weather Bur.) stations. The average annual precipitation was 11.94 inches, which is about 0.5 inch less than the

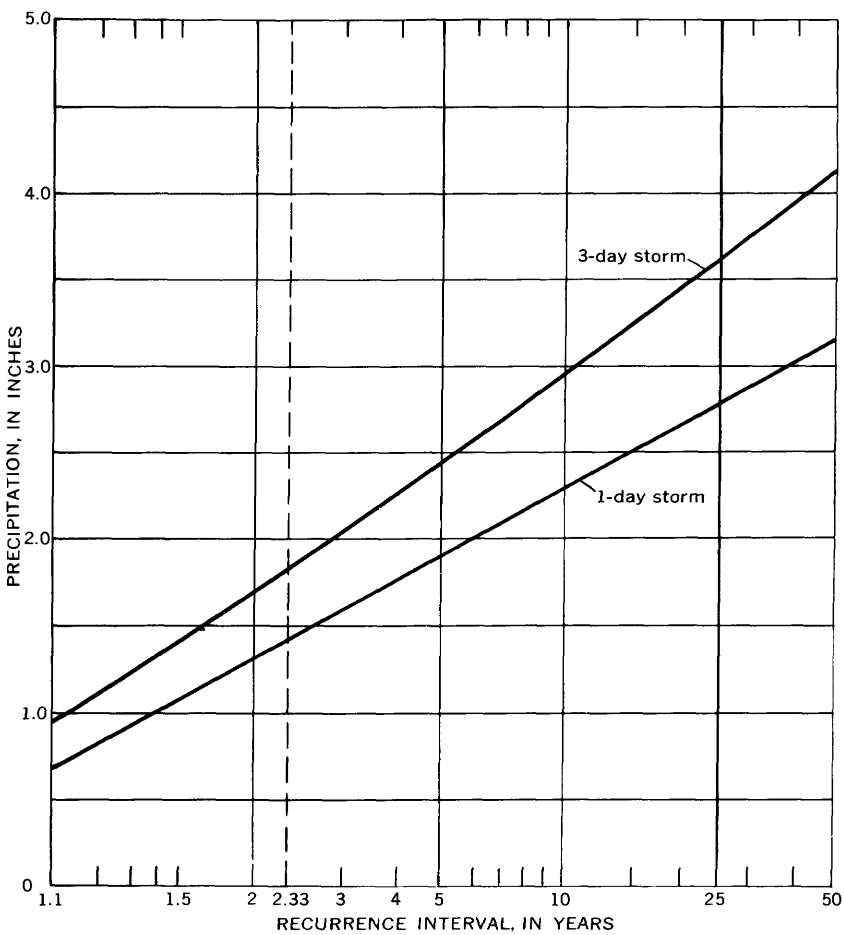

FIGURE 5. — Maximum storm precipitation-frequency curves for the Willow Creek area.

30-year average. The average for the first half of the period was 3.4 inches less than the average for the second half.

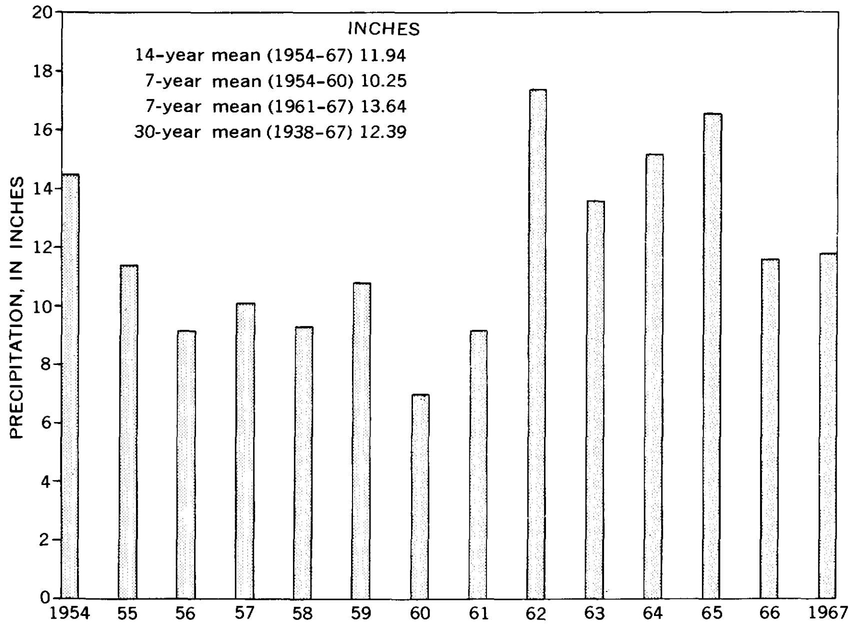

FIGURE 6. — Annual precipitation in the Willow Creek area, 1954–67. Bars show the average of amounts recorded at the following National Weather Service (U.S. Weather Bur.) stations: Glasgow, Frazer, Fort Peck, Haxby, Jordan, Brusett, Telegraph Creek, and Malta.

RUNOFF

Runoff in Willow Creek basin results from either snowmelt or rainstorms. The peak discharge and maximum daily volume in a given year may result from either type of event. Runoff rates are generally high because of the relatively impervious soils in the basin.

Runoff data were obtained by measuring the inflow to a reservoir located at the mouth of each gaged basin[1]. Continuous water-level recorders monitored the reservoir stage. Stage-capacity relations were developed from topographic surveys of the reservoirs and were adjusted for sediment accumulation on the basis of periodic resurveys. Outflow relations were developed from the recession hydrographs and were verified, when possible, by current-meter measurements of outflow, after the inflow had stopped. Inflow was then calculated as change-in-storage plus outflow.

[1]The term "gaged basin(s)" refers to the following upland watersheds where data were obtained by using a reservoir as a runoff- and sediment-collecting device: Burnett, Cactus Flat, Sheepshed, and Triple Crossing. The "gaged basins" are located within the boundaries of Willow Creek basin.

Seepage and evaporation during the inflow periods were considered to be negligible in all reservoirs.

Runoff data collected at three reservoirs are given in tables 2, 3, and 4. Although the recording season varied from year to year, it generally included the months of March through October. Streamflow records (U.S. Geological Survey, "Surface Water Supply of the United States," pt. 6–A, 1954–67) at Willow Creek gaging station show that more than 90 percent of the annual runoff occurs during these months.

ANALYSIS OF DATA

The average seasonal runoff to Burnett, Cactus Flat, and Sheepshed reservoirs was 93.9, 96.5, and 37.5 acre-feet per square mile, respectively, for the 10-year period 1958–67. The average runoff at Burnett reservoir for the 14-year period 1954–67 was 88.1 acre-feet per square mile, and the average at Sheepshed reservoir for the period 1955–67 was 30.9 acre-feet per square mile.

General appearance of Burnett and Cactus Flat drainage basins would suggest that there should be a higher average runoff at Cactus Flat than at Burnett. The relatively impermeable hardpan terraces covering 26 percent of Burnett basin are believed to be a factor in producing this higher than expected runoff. The soils and vegetation of Sheepshed drainage suggest less runoff than at the other two basins. However, the measured difference seems extreme. Part of the difference may be due to an instrumentation deficiency. Sheepshed reservoir was instrumented primarily to measure maximum runoff events, and it is possible that a number of small events were not recorded. As this record of runoff volume is somewhat questionable, it was not used to develop the runoff-volume curves presented in this report. Runoff rates were probably unaffected by this particular instrumentation problem.

The time distribution of runoff must be considered in many management and design decisions. Analysis of reservoir inflow on a single-event basis shows that a major part of the annual inflow usually occurs in a few events. On the average, 34 percent of the annual runoff occurs in response to snowmelt, commonly from one event of several days' to a week's duration. Of the remaining annual runoff (about 66 percent), about half is produced by a single rainstorm in June or July, and half by smaller storms throughout the rest of the summer. Thus, approximately two-thirds of the annual runoff usually occurs from only two events.

Instrumentation used in this study did not provide for determination of instantaneous runoff rates. Average runoff rates were computed by dividing the inflow during a short time interval by that time interval. Although average rates are not directly comparable with instantaneous rates, they may be more meaningful than instantaneous rates for reservoir design, because they show how long the rate was sustained. Rates computed for the Willow Creek area are based on a 30-minute time interval, which is the shortest interval that could be defined with reasonable accuracy for all the records.

An annual flood-frequency curve and two volume-frequency curves were defined for the Willow Creek area. The annual flood-frequency curve (fig. 7) gives the relation between the recurrence interval and the ratio of the maximum annual runoff rate to the mean annual runoff rate. This curve represents the annual series of runoff rates for a 30-minute period and is not interchangeable

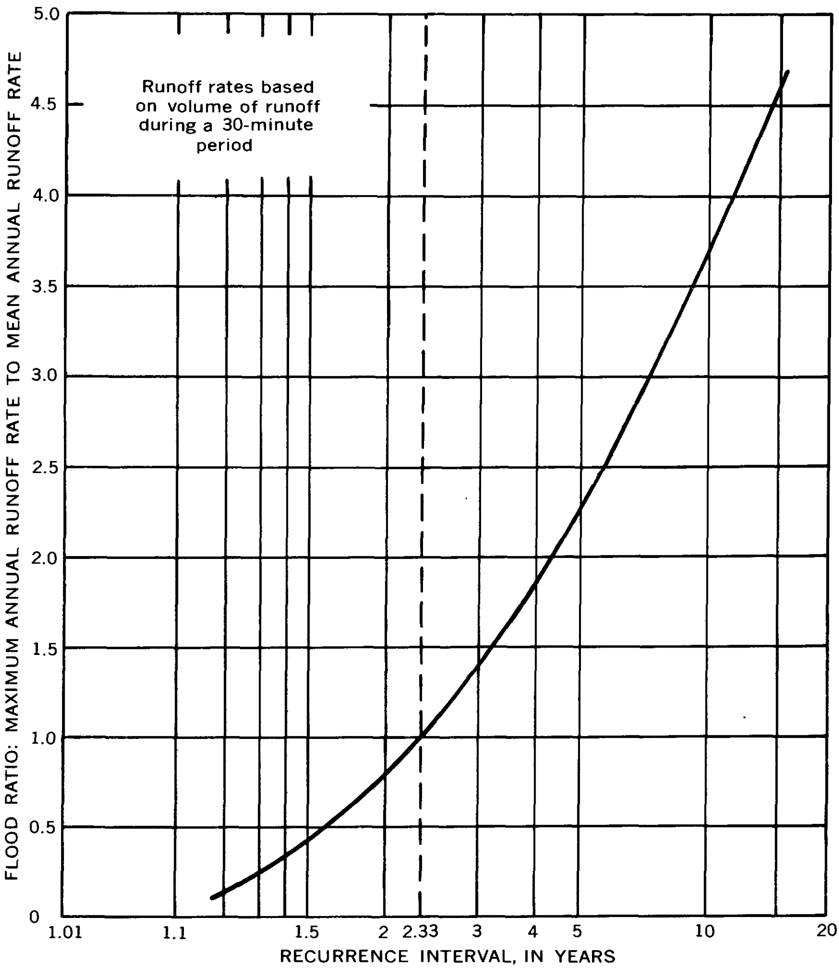

FIGURE 7. — Flood-frequency curve for Willow Creek basin.

with curves representing rates for other time intervals. It is used in conjunction with figure 8 which gives the variation of the mean annual runoff rate with basin size. These curves were developed from the records of Sheepshed, Cactus Flat, and Burnett reservoirs. The paucity of points in figure 8 may cause concern but the relation should give satisfactory estimates of the mean annual floods for basins that are 5 to 11 square miles in area. The mean annual floods of the three gaged basins may be estimated from the curve to within 10 percent of the measured values. Several of the authors' colleagues agree that the measured values indicated in figure 8 are reasonable for the soil, topographic, and vegetative conditions existing in the gaged basins. These basins were originally selected as being representative of the conditions prevailing in Willow Creek basin. Inasmuch as this curve and the related curve in figure 7 are based on a minimum of data, it is extremely important that the use of the limitations listed elsewhere be strictly adhered to.

The two volume-frequency curves (fig. 9) are based on the records of Cactus Flat and Burnett reservoirs. Because of the similarity in the size and the runoff amounts of the two basins, the ordinate values of the two curves are volumes based on the average mean annual volumes. The 6-month-volume curve represents the total volume of runoff for the recording season, which accounts for most of the runoff for the whole year.

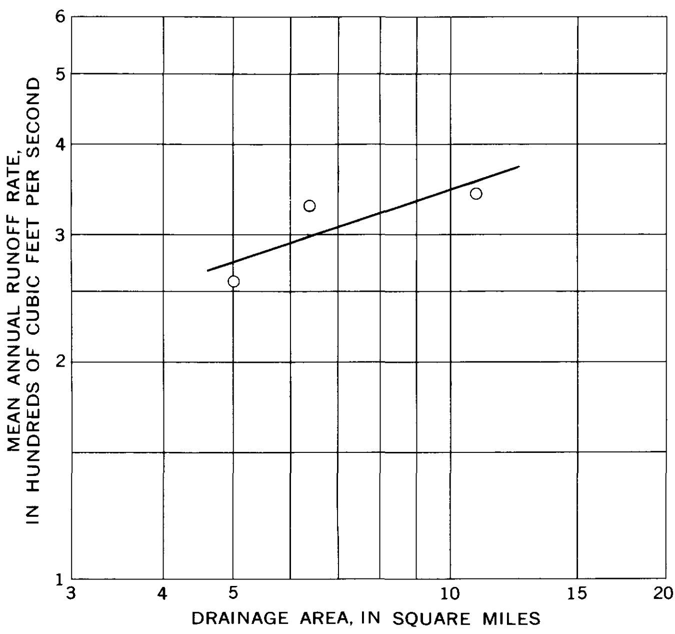

FIGURE 8. — Variation in mean annual runoff rate with drainage area.

To apply the flood-frequency curve to a specific basin, use figure 8 to estimate the mean annual runoff rate for that basin. Then determine the flood ratio for the required recurrence interval from figure 7. The product of the mean annual runoff rate (fig. 8) and the flood ratio (fig. 7) is the estimated runoff rate. A complete flood-frequency curve for a basin can be produced by plotting the runoff rates for several recurrence intervals and fitting a smooth curve through them. The 3-day or 6-month runoff volume of a given recurrence interval can be found for a specific basin by multiplying the basin area by the unit runoff (fig. 9).

The runoff-frequency curves given herein are based on a comparatively small number of records, but, as explained previously, composite curves provide a given degree of accuracy more often than do curves applied on an individual basis. Use of these curves should be restricted to Willow Creek basin and those immediately surrounding areas where the topography, soils, and vegetation are similar to those in Willow Creek basin. The curves represent basins 5 to 11 square miles in area, and their use on basins whose areas are outside this size range is not recommended. The curves should not be extended to higher recurrence intervals.

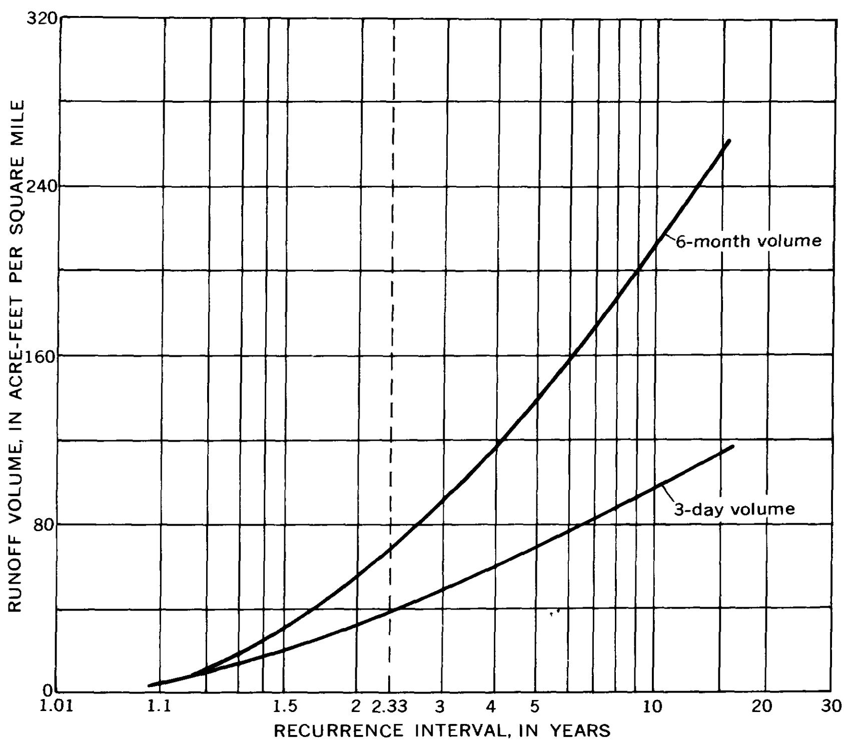

FIGURE 9. — Runoff volume-frequency curves for Willow Creek basin.

TABLE 2. — *Runoff measured in Northwest Burnett reservoir*

Location. — Lat 48°05′ N., long 107°08′ W., SE¼ sec. 24, T. 27 N., R. 35 E., on Lone Tree Creek, about 18 miles upstream from the confluence with Willow Creek, near Glasgow, Mont.
Drainage area. — 5.0 sq mi.
Records available. — 1954–67, summer months only.
Gage. — Water-stage recorder.
Runoff and discharge determinations. — Contents of reservoir and volume of inflow computed from stage-capacity curve of the reservoir. Average discharges determined from runoff hydrograph.
Capacities. — Capacities of the reservoir at the spillway elevation are as follows:

Aug. 1954........146 acre-ft,
Sept. 1955........143 acre-ft,
Sept. 1962........143 acre-ft,
Sept. 1963........143 acre-ft,
June 1968........140 acre-ft.

Maxima. — Maximum storm inflow 512.0 acre-ft, or 102.4 acre-ft per sq mi, July 25–26, 1965.
Remarks. — Records fair, except those with spill which are poor. Has two 24-inch outlet pipes.

Date of flow	Inflow stored (acre-ft)	Spill[1] (acre-ft)	Inflow	
			Total (acre-ft)	Acre-feet per square mile
1954				
May 4–6	0	44.6	44.6	8.9
June 10–12	0	138.0	138.0	27.6
June 29–30	0.8	13.7	14.5	2.9
July 9–10	0.3	15.2	15.5	3.1
Aug. 5–6	6.0	0	6.0	1.2
Aug. 9–10	47.9	0	47.9	9.6
Aug. 15–21	91.6	18.4	110.0	22.0
Sept. 5–6	9.0	0	9.0	1.8
Sept. 15–16	18.0	.5	18.5	3.7
For year	173.6	230.4	404.0	80.8
1955				
May 2–5	0	104.0	104.0	20.8
May 15–19	0	279.0	279.0	55.8
July 25–27	0	59.1	59.1	11.8
For year	0	442.1	442.1	88.4
1956				
Mar. 16–20	0	106.3	106.3	21.3
May 6	0	14.2	14.2	2.8
May 28–29	0	9.2	9.2	1.8
June 22–23	0	38.9	38.9	7.8
July 29–Aug. 3	3.5	24.7	28.2	5.6
Aug. 31	1.8	26.6	28.4	5.7
For year	5.3	219.9	225.2	45.0
1957				
Mar. 19–26	4.6	156.9	161.5	32.3
Apr. 22–24	2.7	9.5	12.2	2.4
May 22–23	2.9	27.6	30.5	6.1
June 9–10	2.9	3.5	6.4	1.3
June 12–17	6.4	29.5	35.9	7.2
June 21–22	2.2	60.8	63.0	12.6
Aug. 30–Sept. 1	3.9	47.5	51.4	10.3
Sept. 4–5	2.8	16.2	19.0	3.8
Sept. 18–19	2.8	13.3	16.1	3.2
Oct. 28–29	2.9	2.3	5.2	1.0
For year	34.1	367.1	401.2	80.2

TABLE 2. — *Runoff measured in Northwest Burnett reservoir* — Continued

Date of flow	Inflow stored (acre-ft)	Spill[1] (acre-ft)	Inflow: Total (acre-ft)	Inflow: Acre-feet per square mile
1958				
July 8–9	1.7	13.3	15.0	3.0
Dec. 3–4	2.4	40.5	42.9	8.6
For year	4.1	53.8	57.9	11.6
1959				
Apr. 18–19	2.6	2.3	4.9	1.0
June 17	0	15.5	15.5	3.1
June 26–27	0	3.6	3.6	.7
July 4	1.9	0	1.9	.4
Sept. 28	2.0	0	2.0	.4
Oct. 6	2.3	4.3	6.6	1.3
Oct. 9	2.4	1.3	3.7	.7
For year	11.2	27.0	38.2	7.6
1960				
Mar. 17–23	6.1	370.1	376.2	75.2
Apr. 29–May 1	3.4	67.3	70.7	14.1
June 22	5.1	7.9	13.0	2.6
For year	14.6	445.3	459.9	91.9
1961				
Apr. 24	5.8	0.0	5.8	1.2
May 30–31	10.0	7.0	17.0	3.4
June 13	1.8	.0	1.8	.4
June 18	2.5	.5	3.0	.6
July 31	5.0	1.2	6.2	1.2
Sept. 2	13.5	8.1	21.6	4.3
Sept. 18	6.4	.4	6.8	1.4
Oct. 31	6.1	.5	6.6	1.3
For year	51.1	17.7	68.8	13.8
1962				
Mar. 21–26	43.8	115.4	159.2	31.8
May 13–14	9.0	34.8	43.8	8.8
May 15	.2	.2	.4	.1
May 16	17.6	23.5	41.1	8.2
May 20–22	43.1	65.2	108.3	21.7
June 3–5	42.0	47.9	89.9	18.0
June 14–15	2.3	12.3	14.6	2.9
June 20	.9	.6	1.5	.3
June 22–23	17.6	38.7	56.3	11.3
July 2	.9	1.3	2.2	.4
July 13–14	120.0	225.0	[2]345.0	69.0
Oct. 15–16	11.4	15.2	26.6	5.3
For year	308.8	580.1	888.9	177.8
1963				
Before Feb. 28	4.2	5.1	[2]9.3	1.9
Feb. 28–Mar. 2	.6	10.0	10.6	2.1
Apr. 10	2.3	.4	2.7	.5
Apr. 17–18	2.8	9.8	12.6	2.5
May 9–13	5.8	45.2	51.0	10.2
June 5–7	25.4	61.6	87.0	17.4
June 21–22	25.0	58.6	83.6	16.7
June 28–29	8.8	25.3	34.1	6.8
July 10	19.7	28.0	47.7	9.5
Aug. 25–26	9.0	50.6	59.6	11.9
Sept. 3	.2	12.3	12.5	2.5
For year	103.8	306.9	410.7	82.0

TABLE 2. — *Runoff measured in Northwest Burnett reservoir* — Continued

Date of flow	Inflow stored (acre-ft)	Spill[1] (acre-ft)	Inflow: Total (acre-ft)	Inflow: Acre-feet per square mile
1964				
Mar. 30–Apr. 1	2.2	6.1	8.3	1.7
Apr. 8–9	5.1	16.4	21.5	4.3
Apr. 26	2.6	.8	3.4	.7
May 3	40.1	27.8	67.9	13.6
May 3–4	83.6	60.2	143.8	28.8
June 18–19	40.1	45.3	85.4	17.1
June 20	10.2	29.6	39.8	8.0
July 3	20.9	40.6	61.5	12.3
July 10	4.1	5.5	9.6	1.9
Aug. 20	15.9	15.6	31.5	6.3
For year	224.8	247.9	472.7	94.7
1965				
Apr. 12	86.2	12.2	98.4	19.7
Apr. 22	.3	.0	.3	.1
May 6–7	126.4	188.8	315.2	63.0
May 30–31	2.6	1.9	4.5	.9
June 1	3.3	10.6	13.9	2.8
June 13	1.6	1.6	3.2	.6
June 14–16	37.1	59.6	96.7	19.3
June 25–26	127.6	384.4	512.0	102.4
June 29	1.8	6.1	7.9	1.6
July 10	18.6	34.5	53.1	10.6
Aug. 5–6	82.4	77.9	160.3	32.1
Sept. 4	1.8	1.8	3.6	.7
Sept. 9	.1	.0	.1	.0
Sept. 15	.3	.0	.3	.1
For year	490.1	779.4	1,269.5	253.9
1966				
Mar. 12–16	2.0	140.9	142.9	28.6
May 14–16	1.6	8.7	10.3	2.1
July 2–5	2.5	107.5	110.0	22.0
July 12–13	137.8	118.2	256.0	51.2
Oct. 21–22	6.7	4.3	11.0	2.2
For year	150.6	379.6	530.2	106.1
1967				
Up to Mar. 3	52.6	43.7	96.3	19.3
Mar. 8–9	16.1	44.9	61.0	12.2
Mar. 12–Apr. 4	34.3	38.9	73.2	14.6
Apr. 6–7	.1	16.1	16.2	3.2
Apr. 23	.2	.0	.2	.0
Apr. 25–May 2	2.0	126.0	128.0	25.6
June 12–15	.9	17.0	17.9	3.6
June 18	.1	.0	.1	.0
Sept. 13–15	6.8	61.3	68.1	13.6
Oct. 1	.7	.2	.9	.2
Oct. 5–6	1.4	33.7	35.1	7.0
For year	115.2	381.8	497.0	99.3

[1]Includes pipe outflow. All spill goes to waterspreader.
[2]Recorder not operating; amounts based on high-water marks.

TABLE 3.—*Runoff measured in Cactus Flat reservoir*

Location.—Lat 47°59′ N., long 106°46′ W., E½ sec. 24, T. 26 N., R. 38 E., on Wilderness Coulee about 1 mile upstream from the confluence with Willow Creek, near Glasgow, Mont.
Drainage area.—Contributing area 6.4 sq mi.
Records available.—1958–67, summer months only.
Gage.—Water-stage recorder.
Runoff and discharge determinations.—Contents of reservoir and volume of inflow computed from stage-capacity curve of the reservoir. Average discharges determined from runoff hydrograph.
Capacities.—Original capacity 254 acre-ft at spillway (gage height 6.5 ft), survey of July 30, 1958; capacity 185.6 acre-ft, survey of Sept. 9, 1962; capacity 176.8 acre-ft, survey of September 29, 1963; capacity 169 acre-ft, survey of October 10, 1964; capacity 159 acre-ft, survey of October 6, 1966.
Maxima.—Maximum storm inflow 1,177.4 acre-ft, or 184.0 acre-ft per sq mi, May 18–25, 1960.
Remarks.—Records fair, except those with spill which are poor. Has two 24-inch outlet pipes.

Date of flow	Outflow (acre-ft)		Total outflow (acre-ft)	Inflow stored (acre-ft)	Inflow	
	Lower pipe	Upper pipe and spillway			Total (acre-ft)	Acre-feet per square mile
1958						
Dec. 3–4			0.0	27.5	27.5	4.3
For year				27.5	27.5	4.3
1959						
Before Mar. 7				206.0	206.0	32.2
Oct. 8–9			0.0	47.6	47.6	7.4
Oct. 14	2.3		2.3	5.2	7.5	1.2
For year			2.3	258.8	261.1	40.8
1960						
Mar. 18–25	397.4	664.7	1,062.1	115.3	1,177.4	184.0
Apr. 24–25			.0	2.7	2.7	.4
Apr. 28–May 1	11.3		11.3	22.0	33.3	5.2
For year			1,073.4	140.0	1,213.4	189.6
1961						
June 13–14	7.8		7.8	93.5	101.3	15.8
June 18			.0	1.7	1.7	.3
Sept. 2			.0	3.5	3.5	.6
Sept. 9–10			.0	9.6	9.6	1.5
Sept. 11			.0	4.0	4.0	.6
Sept. 18			.0	.8	.8	.1
For year			7.8	113.1	120.9	18.9
1962						
Mar. 21–22	21.4		21.4	100.2	121.6	19.0
Mar. 24–26	57.4		57.4	17.0	74.4	11.6
May 13			.0	.3	.3	.0
May 21–23			13.9	79.3	[1]93.2	14.6
July 13–14	170.0	610.0	780.0		[2]780.0	121.9
For year			872.7	196.8	1,069.5	167.1

TABLE 3. — *Runoff measured in Cactus Flat reservoir* — Continued

Date of flow	Outflow (acre-ft)		Total outflow (acre-ft)	Inflow stored (acre-ft)	Inflow	
	Lower pipe	Upper pipe and spillway			Total (acre-ft)	Acre-feet per square mile
1963						
May 12–13	40.6		40.6	0.0	40.6	6.3
June 5–6	36.0	6.4	42.4	176.7	219.1	34.2
June 23–July 1	82.6		82.6	9.1	91.7	14.3
July 10–11	61.0	55.9	116.9	190.5	307.4	48.0
Aug. 25–26	13.9	1.6	15.5	147.2	162.7	25.4
For year			298.0	523.5	821.5	128.2
1964						
Mar. 18			15.0	0.0	[1]15.0	2.3
May 2–4	84.2	61.6	145.8	226.5	[1]372.3	58.2
For year			160.8	226.5	387.3	60.5
1965						
Apr. 3–15	441.5	216.8	658.3	67.5	725.8	113.4
May 5–10	50.6	185.5	236.1	258.4	494.5	77.3
June 14–15	8.2		8.2	5.3	13.5	2.1
July 4–5	6.8		6.8	7.4	14.2	2.2
July 7–8	13.6	2.6	16.2	113.9	130.1	20.3
July 10–11	20.7	14.1	34.8	141.2	176.0	27.5
Aug. 6–7	78.0	9.5	87.5	61.3	148.8	23.2
For year			1,047.9	655.0	1,702.9	266.0
1966						
Mar. 12–17	105.8		105.8	10.7	116.5	18.2
May 14	2.2		2.2	6.2	8.4	1.3
July 2–4	20.6		20.6	6.8	27.4	4.3
July 13			.0	.1	.1	.0
Aug. 20–21	11.6		11.6	4.3	15.9	2.5
For year			140.2	28.1	168.3	26.3
1967						
Mar. 1–3	88.1		88.2	10.5	98.7	15.4
Mar. 9	9.6		9.6	7.2	16.8	2.6
Mar. [3]	53.0		53.0	125.0	[1]178.0	27.8
Apr. 14			.0	.8	.8	.1
May 2	48.0		48.0	63.5	[1]111.5	17.4
Sept. 14				.8	.8	.1
For year			198.8	207.8	406.6	63.4

[1]Clock not operating ; amounts estimated from range of chart trace.
[2]Recorder not operating ; amounts estimated from high-water marks.
[3]Date uncertain.

TABLE 4. — *Runoff measured in Sheepshed reservoir*

Location. — Lat 47°53′ N., long 107°09′ W., SE¼ sec. 26, T. 25 N., R. 35 E., on Willow Creek about 56 miles upstream from gaging station near Glasgow, Mont.
Drainage area. — 10.8 sq mi.
Records available. — 1955–67, summer months only.
Gage. — Water-stage recorder.
Runoff and discharge determinations. — Contents of reservoir and volume of inflow computed from stage-capacity curve of the reservoir. Average discharges determined from runoff hydrograph.
Capacities. — Original capacity 550 acre-ft at spillway (gage height 16.1 ft), survey of Sept. 24, 1955; capacity 518 acre-ft, survey of Sept. 14, 1962; capacity 488 acre-ft, survey of June 25, 1968.

TABLE 4. — *Runoff measured in Sheepshed reservoir*—Continued

Maxima. — Maximum storm inflow 777.5 acre-ft, or 72.0 acre-ft per sq mi, July 13–14, 1962.
Remarks. — Record poor. Some inflow not recorded because of recorder location relative to low point in reservoir and outlet pipe. Has 6-inch and 21-inch outlet pipes.

Date of flow	Outflow (acre-ft)		Total outflow (acre-ft)	Inflow stored (acre-ft)	Inflow	
	Pipe[1]	Spillway[1]			Total (acre-ft)	Acre-feet per square mile
1955						
July 26–29	81.0		81.0	28.0	109.0	10.1
For year			81.0	28.0	109.0	10.1
1956						
Mar. 24	1.3		1.3	42.5	43.8	4.1
July 3–4	15.4		15.4	79.9	95.3	8.8
Aug. 29	.2		.2	.8	1.0	<.1
For year			16.9	123.2	140.1	13.0
1957						
Aug. 19			0.0	23.6	23.6	2.2
Sept. 1–4			.0	5.8	5.8	.5
For year			.0	29.4	29.4	2.7
1958						
June 9			0.0	31.3	31.3	2.9
July 30	0.1		.1	14.7	14.8	1.4
For year			.1	46.0	46.1	4.3
1959						
Mar. 2	82.9		82.9	98.8	[3]181.7	16.8
Apr. 17	3.2		3.2	.8	4.0	.4
Apr. 26–27			.0	3.6	3.6	.3
May 2–3			.0	5.5	5.5	.5
May 9–10			.0	3.0	3.0	.3
May 19			.0	2.2	2.2	.2
Oct. 20			.0	1.3	1.3	.1
For year			86.1	115.2	201.3	18.6
1960						
Mar. 18–22	374.1		374.1	219.6	593.7	55.0
Apr. 29[2]			.0	3.2	[3]3.2	.3
June 22			.0	16.8	16.8	1.6
For year			374.1	239.6	613.7	56.8
1961[4]						
1962						
Mar. 20–26	34.7		34.7	101.6	[3]136.3	12.6
Mar. 22			16.0	22.5	38.5	3.6
July 13–14	74.3	102.1	176.4	601.1	777.5	72.0
July[2]	58.7		58.7	45.2	[3]103.9	9.6
July[2]	106.4		106.4	24.8	[3]131.2	12.1
For year			392.2	795.2	1,187.4	109.9
1963						
Feb. 25–27	35.9		35.9	33.1	69.0	6.4
June 21–22	56.2		56.2	151.8	208.0	19.2
June 29–30	4.6		4.6	2.1	6.7	.6
July 10	65.2		65.2	15.0	80.2	7.4
For year			161.9	202.0	363.9	33.6

TABLE 4. — *Runoff measured in Sheepshed reservoir* — Continued

Date of flow	Outflow (acre-ft)		Total outflow (acre-ft)	Inflow stored (acre-ft)	Inflow	
	Pipe[1]	Spillway[1]			Total (acre-ft)	Acre-feet per square mile
1964						
May 4	31.6	.....	31.6	73.9	105.5	9.8
June 18–19	53.8	.....	53.8	204.9	258.7	24.0
June 20	22.4	.....	22.4	—11.5	10.9	1.0
For year	.....	.....	107.8	267.3	375.1	34.8
1965						
Mar. 19	6.4	.....	6.4	12.1	18.5	1.7
Apr. 1–3	119.3	.....	119.3	17.3	136.6	12.6
Apr. 8–9	4.3	.....	4.3	1.1	5.4	.5
Apr. 10–11	30.6	.....	30.6	.1	30.7	2.8
Apr. 12–14	98.3	.....	98.3	40.2	138.5	12.8
May 6–8	71.8	.....	71.8	147.4	219.2	20.3
For year	.....	.....	330.7	218.2	548.9	50.7
1966						
Mar. 10–12	68.4	.....	68.4	32.6	101.0	9.4
For year	.....	.....	68.4	32.6	101.0	9.4
1967						
Feb. 25–Mar. 2	80.6	.....	80.6	26.0	106.6	9.9
Mar. 21–24	247.5	.....	247.5	178.8	426.3	39.5
Apr. 27–29	33.3	.....	33.3	22.0	55.3	5.1
May 1–2	21.3	.....	21.3	8.4	29.7	2.8
For year	.....	.....	382.7	235.2	617.9	57.3

[1]Water returns to channel.
[2]Date uncertain.
[3]Clock not operating; amounts estimated from range of chart trace.
[4]No runoff recorded.

EROSION AND SEDIMENT YIELD

The most notable examples of channel erosion are the many deep gullies and headcuts along the lower reaches of Willow Creek and its tributaries. The gullies are in all stages of development and contribute sediment directly to the main channels. Hardpan slicks and semislicks on the stream terraces show little evidence of sheet and rill erosion and probably serve as a barrier to sediment transport because of their low gradient. Steeper upland slopes show various amounts of erosion, depending on the soils and the amount of vegetative cover. The coarser sediment removed from the upland slopes is often redeposited within a short distance and does not reach the main channels. This is especially noticeable where the grass is moderately heavy.

Sediment data were obtained by surveying selected reservoirs. The reduction in storage capacity shown by the surveys was taken as the volume of sediment deposited for the intervening time period. No adjustments were made for sediment that may have escaped with spill or for increases in reservoir capacity due to compaction of older sediment. These losses are believed to be small, for the reasons discussed by Peterson (1962).

Suspended-sediment volumes passing the Willow Creek gaging station were determined by taking representative samples of the flow. (See "Quality of Surface Waters of the United States," Pt. 6, "Missouri River Basin" [U.S. Geological Survey, 1954–63] for methods of sampling and computing sediment volumes.)

The amounts of sediment measured in four reservoirs in Willow Creek basin are given in table 5. Sediment amounts measured at three other reservoirs for the period 1952–55 were given by Peterson (1962). Measurements at these three reservoirs were discontinued after 1955 because of their high frequency of spill. Suspended-sediment amounts measured at the Willow Creek gaging station are given in table 6.

The average annual rate of sediment deposition in the measured reservoirs varied from 0.09 acre-foot per square mile at Burnett to 2.00 acre-feet per square mile at Triple Crossing for the periods of record. This rate variation presumably reflects the difference in the sediment-producing characteristics of the four basins.

TABLE 5. — *Sediment yield during periods between surveys*

Reservoir	Period	Sediment: Total, Acre-feet	Sediment: Total, Acre-feet per square mile	Sediment: Annual, Acre-feet per square mile
Northwest Burnett.	Aug. 1954–Sept. 1955	3.00	0.6	......
	Sept. 1955–Sept. 1962	.00	.0	......
	Sept. 1962–Sept. 1963	.02	.0	......
	Sept. 1963–June 1968	3.13	.6	......
	Aug. 1954–June 1968	6.15	1.2	0.09
Cactus Flat	July 1958–Sept. 1962	69.20	10.81	......
	Sept. 1962–Sept. 1963	8.62	1.35	......
	Sept. 1963–Oct. 1964	5.76	.90	......
	Oct. 1964–Oct. 1966	8.99	1.40	......
	July 1958–Oct. 1966	92.57	14.46	1.81
Sheepshed	Sept. 1955–Sept. 1962	33.64	3.12	......
	Sept. 1962–June 1968	25.33	2.34	......
	Sept. 1955–June 1968	58.97	5.46	.42
Triple Crossing.	May 1960–Oct. 1964	421.0	9.98	......
	Oct. 1964–June 1968	63.6	1.51	......
	May 1960–June 1968	484.6	11.49	1.44

The amount of sediment deposited in Triple Crossing reservoir for the period 1964–1968 was considerably less than the amount deposited during the period 1960–64. Examination of the construction records of the Bureau of Land Management show that the drainage area contributing to Triple Crossing reservoir was diminished by nearly 50 percent with the construction of numerous small reservoirs during 1965–66. Much of the sediment that otherwise would have been deposited in Triple Crossing reservoir was probably retained by these newer reservoirs. The rate shown in table 5 for this reservoir was adjusted to 2.00 acre-feet per square mile on the basis of the Cactus Flat record. Computed sedimentation rates for the various vegetation types, given later in this report, are based on a rate of 2.00 acre-feet per square mile from Triple Crossing basin. The reader is reminded that the quantity of sediment deposited in a reservoir is not a measure of the total sediment movement in the basin. Total sediment movement is the quantity of sediment measured in the reservoir plus the sediment deposited within the basin plus the sediment lost through spill.

TABLE 6.—*Annual suspended-sediment load and stream discharge measured at Willow Creek gaging station*[1]

Calendar year	Suspended-sediment load[2] (acre-ft)	Stream discharge (acre-ft)
1954	661	30,815
1955	934	53,182
1956	176	9,113
1957	203	16,452
1958	8	2,302
1959	522	48,247
1960	336	43,062
1961	58	4,562
1962	1,662	104,292
1963	536	47,217
1964	[3]492	43,982
1965		114,700
1966		11,150
1967		37,300
Total	5,588	566,376
11-year average	508	36,657
14-year average		40,455

[1]From U.S. Geol. Survey reports on surface water and quality of surface water, in the United States (1954–67).
[2]Based on a density of 1,750 tons per acre-foot.
[3]Through September 30.

RELATION TO DISTRIBUTION OF VEGETATION

The range in sediment yields suggests that there are significant differences in the sediment-producing characteristics of these basins; thus, the use of a simple average of the rates for estimating purposes may not be adequate. A statistical determination of the significant characteristics was not possible because of insufficient data. The reliability of vegetative measurements as indices of the runoff and sediment yields of an area was tested by Branson and Owen (1970), and the possibility of using the distribution of vegetation as a guide for estimating sediment yield in Willow Creek basin was investigated.

The relative amounts of the major vegetation types in each of the study basins and for the whole of Willow Creek basin were determined from vegetation maps provided by the Bureau of Land Management and are shown in table 7. The measured sediment yields for these basins are also shown. The vegetation in Sheepshed basin is about 76 percent grassland and 24 percent sagebrush; in Burnett basin the vegetation is about 74 percent grassland and 26 percent saltbush. Although both basins have low sediment yields compared with the other gaged basins, the sediment yield at Sheepshed is 5 times that at Burnett. This suggests that the sediment-producing characteristics of the two areas — the one supporting sagebrush and the other saltbush — are diverse. Data collected by I. S. McQueen and K. W. Ratzlaff (written commun., 1969) on soil erodibility in conjunction with infiltrometer tests show the same diversity. (See McQueen, 1963, for description of equipment and method.) Soil particles detached from the surface by simulated raindrop impact were collected and weighed. Figure 10 shows the relative amounts of sediment detached from soils supporting three vegetation types. Sediment amounts obtained by this method indicate the relative ease with

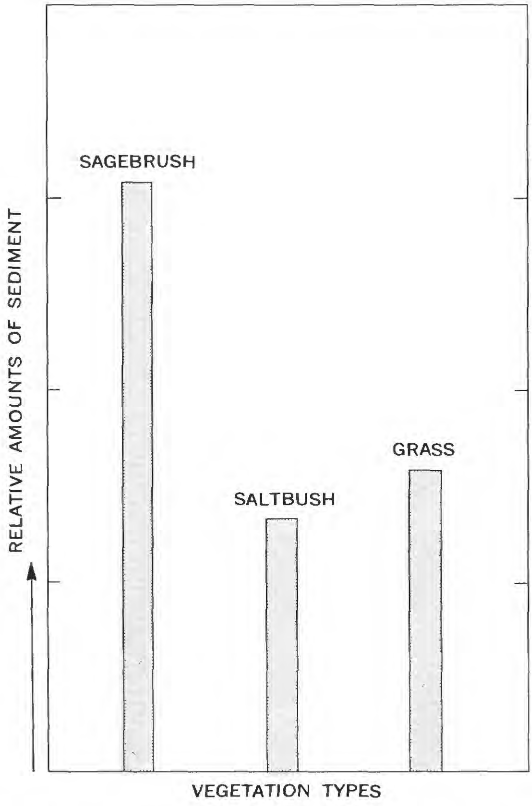

FIGURE 10. — Relative amounts of particles detached from soils supporting different vegetation types.

which particles are detached and moved from the soil surface and represent the erosion potential of the soil.

TABLE 7.—*Distribution of major vegetation types in the study basins and measured sediment yields*

Basin	Amount of basin covered by indicated vegetation type (percent)					Sediment yield (acre-ft/mi²)
	Grass	Sage-brush	Salt-bush	Grease-wood	Other[1]	
Burnett	74	0	26	0	0	0.09
Triple Crossing	60	5	9	26	0	2.00
Sheepshed	76	24	0	0	0	.44
Cactus Flat	0	84	10	0	6	1.81
Willow Creek	34	27	14	18	7	[2]1.40

[1]Annual weeds, waste, barren.
[2]Estimated.

Sagebrush in Willow Creek basin is generally found on the steeper, shale slopes (fig. 11). The erosiveness of the sagebrush areas is indicated by the Cactus Flat data. The saltbush type occurs mainly on the old unflooded terraces that have developed "slick" and "semislick" areas (fig. 12). The soil chemistry of these areas is such that infiltration is greatly restricted, and a smooth silty crust forms on the surface (Branson and others, 1962).

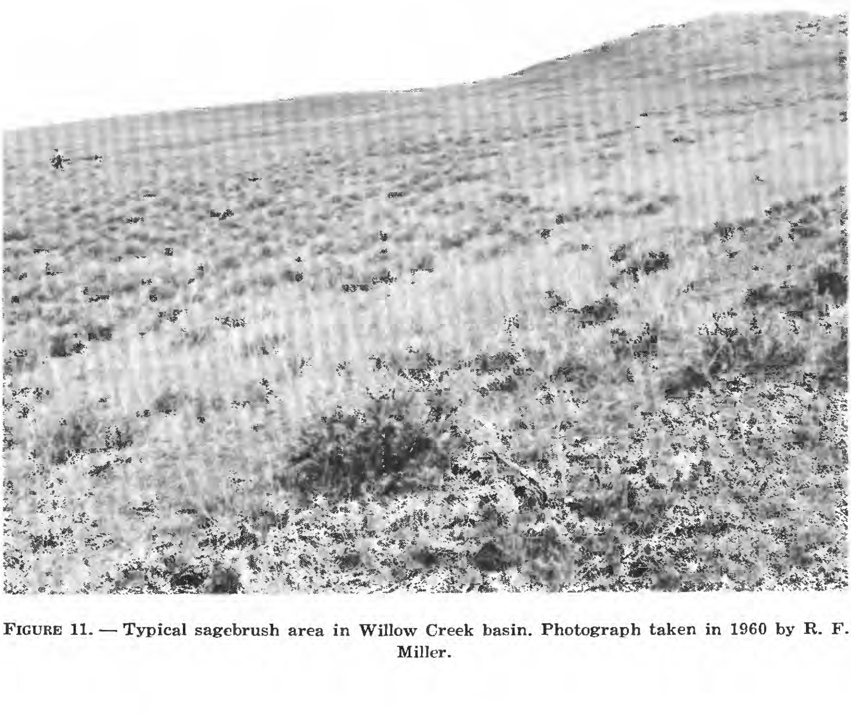

FIGURE 11.—Typical sagebrush area in Willow Creek basin. Photograph taken in 1960 by R. F. Miller.

FIGURE 12. — Typical hardpan terrace with a "slick" area in the foreground and a "semislick" area in the background. These areas produce high runoff but little sediment. Photograph taken in 1960 by R. F. Miller.

The result is that a high percentage of the precipitation falling on these areas runs off, but the crust and low gradient tend to limit the erosion and inhibit the movement of sediment from the steeper slopes to the main channels. The high runoff and low sediment yields measured at Burnett basin suggest that the incidence of the saltbush type may have a significant effect on the hydrology of an area.

The preceding evidence suggests that the relative amounts of major vegetation types in an area may be used as a guide for applying sedimentation rates to the area. An average sedimentation rate was computed for each major vegetation type that occurred in a gaged basin. The measured rate for each basin was weighted by the percentage of basin area covered by a given vegetation type (table 7). The four-basin average of these weighted values is the computed sedimentation rate (table 8). Sedimentation rates were not computed for annual weeds, waste, and barren areas, as these types were mapped in only a small part of one gaged basin. These types generally occur on steep slopes with loose fine-grained surface material, and they appear to have a higher sedimentation rate than any of the other types. A sedimentation rate of 3.5 acre-feet per square mile or greater should be applied where annual weeds, waste, and barren types occur. The rate shown for greasewood applies to upland sites only. Greasewood sites on alluvial bottomlands probably have a sedimentation rate similar to the saltbush type.

The computed sediment rates, shown in table 8, were applied to the uncontrolled areas of Willow Creek basin. It is assumed that 95 percent of the sediment from the controlled areas is retained by reservoirs. The computed estimate of sediment yield from the average uncontrolled area for the period 1954–64 is 507 acre-feet per year. This compares closely with the 500 acre-feet per year[2] measured at the gaging station.

TABLE 8. — *Computed sediment yields associated with major vegetation types*

Vegetation type	*Annual sediment yield (acre-ft/mi²)*
Grass	0.76
Sagebrush	1.51
Saltbush	.88
Greasewood, upland	2.00
Greasewood, bottomland	.90
Weeds, waste, barren	3.50

METHOD OF ESTIMATING SEDIMENT YIELD

To estimate the sediment yield for a particular basin, determine the number of square miles of each vegetation type in the basin from figure 2. Multiply each value by its corresponding sedimentation rate from table 8. The sum of these products is the estimated annual sediment yield of the basin, in acre-feet. Non-average local conditions, such as extreme gullying, may dictate adjustment of this value for a more realistic estimate.

In using vegetation type as an indicator of sediment yield, the vegetation is assumed to represent the net result of integrating all factors which affect plant growth in an area. The degree of erosion in the area is related to some of the same factors and may itself be a factor affecting plant growth. Plants survive over a range of conditions, and different types often coexist. As this method considers only major types, the results are partly dependent on how delineations between types were mapped in areas where two or more types are present in nearly equal densities. It is possible that more reliable estimates would be obtained if the vegetation types were subdivided; however, the gaged basins do not represent an adequate number of subdivisions for this

[2]Datum from table 6 adjusted for sediment that passed through the reservoirs.

purpose. The method, as presented, provides a means of projecting the sedimentation data from small basins to a larger area for the purpose of making realistic sediment-yield estimates. The sedimentation rates given are averages derived from a minimum of data and should be used accordingly.

CONSERVATION STRUCTURES

Reservoirs and waterspreaders, such as those in Willow Creek basin, do not always function as intended, either individually or as a system. Indeed, under certain combinations of conditions, a structure system can actually aggravate the flooding it is supposed to alleviate. Therefore, a periodic evaluation of the effects of the system is desirable to determine whether a structure's performance is adequate or whether additional (or alternate) measures are needed. These evaluations should also be helpful in planning future structure systems.

The effects of the conservation structures in Willow Creek basin are difficult to assess because construction continued throughout the data-collection period. Each new reservoir changed the size of the contributing area of the basin, making it difficult to relate data to a specific area. It is in this context that the following evaluations are offered.

EFFECTS ON RUNOFF

The most significant effect of reservoirs and waterspreaders should be the reduction of peak discharges. As no records were collected prior to the beginning of construction, a "before" and "after" comparison was not attempted. However, there is evidence that the flow regime of Willow Creek has changed. The width of the channel at the gaging station (fig. 2) has narrowed significantly since 1955 (fig. 13). This change of channel geometry presumably occurred in response to reduced peak discharges and prolonged periods of low flow brought about by the detention reservoirs constructed in the basin.

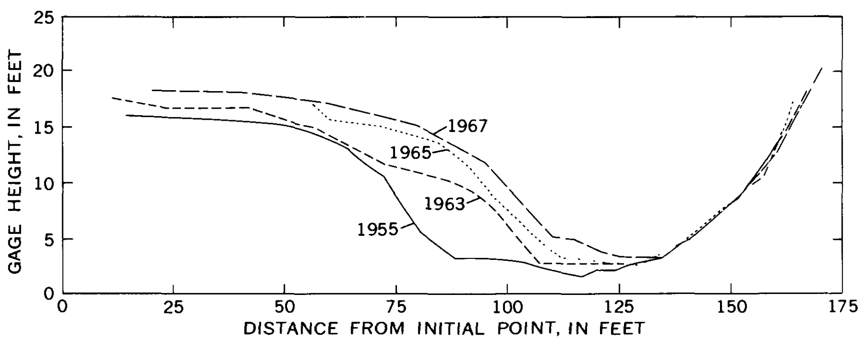

FIGURE 13. — Cross-sections of the Willow Creek channel at the gaging station, showing a significant change in shape during the period 1955–67.

The highest discharge recorded at the Willow Creek gaging station during the period 1954–67 was 12,400 cfs (cubic feet per second) on July 14, 1962. Inspection of a number of reservoirs after this flood indicated that most of the reservoirs whose outflow would contribute directly to the flood peak were nearly filled, but few, if any, spilled significantly. The composite pipe outflow from these reservoirs was about 2,180 cfs. After reducing the measured peak by 2,180 cfs, the unit discharge for the 197 square miles of uncontrolled area between the reservoirs and the gaging station was computed as 52 cfs per square mile. The same computations were made for the smaller Beaver Creek drainage. An indirect measurement of discharge was made at a point near its confluence with Willow Creek, and the flow was computed as 4,590 cfs. This is about 68 cfs per square mile of uncontrolled area after subtraction of reservoir outflow. Based on a logarithmic plot of unit discharge and drainage area, the projected unit discharge from 538 square miles is 42 cfs per square mile. At the rate of 42 cfs per square mile, and had there been no reservoirs to detain flow, the discharge at the gaging station would have been 22,600 cfs. Based on these estimates, it appears that the conservation structures in the basin reduced the peak discharge of this storm about 45 percent.

Reservoirs and waterspreaders reduce the runoff volume from Willow Creek basin, though not by a major amount. About 17 percent of the basin is controlled by waterspreading systems (dikes and supply reservoirs), which contribute virtually no runoff to Willow Creek. Reservoirs reduce runoff volume by increasing the time during which seepage and evaporation losses can occur. These losses were not evaluated because of insufficient data. Permanent storage in the reservoirs is small compared with their total runoff volume. On the basis of the average runoff measured at Burnett and Cactus Flat reservoirs, the gross annual runoff from Willow Creek basin is estimated to be about 49,000 acre-feet. The average annual runoff measured at the gaging station is about 18 percent less than this. The difference represents all losses incurred, including losses due to the presence of structures and normal transmission losses. Channel losses are believed to be small, owing to the low permeability of the fine-textured alluvium in which the channels are incised. No data are available for evaluating transmission losses or the extent to which these losses are affected by the structures.

The primary function of Willow Creek reservoirs is to supply water for livestock and irrigation and to reduce flood peaks. An inherent weakness of reservoirs is that they gradually fill with sediment, thus reducing their capacity to function as intended.

Some of the smaller retention reservoirs in high-sediment-yield areas have become filled in just 3 to 4 years. The retention of sediment reduces downstream pollution for the present, but it could result in the destruction of the reservoirs and the sudden release of this sediment later. Because it is generally too costly to attempt to prolong the life of reservoirs by removal of the sediment, the effective life of the system is determined by the rate at which sediment is delivered to the reservoirs.

EFFECTS ON SEDIMENT YIELD

The effect of reservoirs on downstream sediment yield is indicated by the data from Triple Crossing reservoir. The 1965–68 measurement period, during which a number of small reservoirs were built in the basin, shows a large decrease in sediment yield compared with that during the 1960–64 period. Much of this reduction is believed to be due to retention of the sediment by the small reservoirs, although some may be due to runoff differences. Measurements at the gaging station on the main stem of Willow Creek indicate a significant reduction in sediment concentration from 1954 to 1964. The relation of monthly sediment load and monthly runoff volume for two 3-year periods—the years 1954–56 and 1962–64 — was determined by least-squares regressions (fig. 14). The curves are nearly parallel and show, on the average, 55 percent less sediment per unit of runoff during the 1962–64 period. This decrease in sediment concentration is presumably due to the retention of sediment in the additional reservoirs constructed during the period 1957–64.

It is not known how much sediment has been retained by the reservoirs in Willow Creek basin, as only a few reservoirs have been measured. Based on the distribution of vegetation types, the entire basin is estimated to yield an average of 751 acre-feet of sediment annually. Eleven years of suspended-sediment discharge (1954–64) at Willow Creek gaging station show that about 500 acre-feet per year was removed from the basin, assuming trap efficiency of 95 percent. This means that a total of 251 acre-feet of sediment was retained by the reservoirs each year.

If one assumes that 251 acre-feet of sediment is retained each year, the composite annual loss of original reservoir capacity in Willow Creek basin is 1.6 percent, based on the average storage capacity of reservoirs constructed through 1963. The four gaged basins show a composite annual loss of original capacity of 1.6 percent, also. At the rate of 1.6 percent, the average life of the reservoirs would be about 62 years; however, the useful life would be much shorter because reservoirs begin to lose their effectiveness as soon as the capacity allotted to sediment storage has been filled.

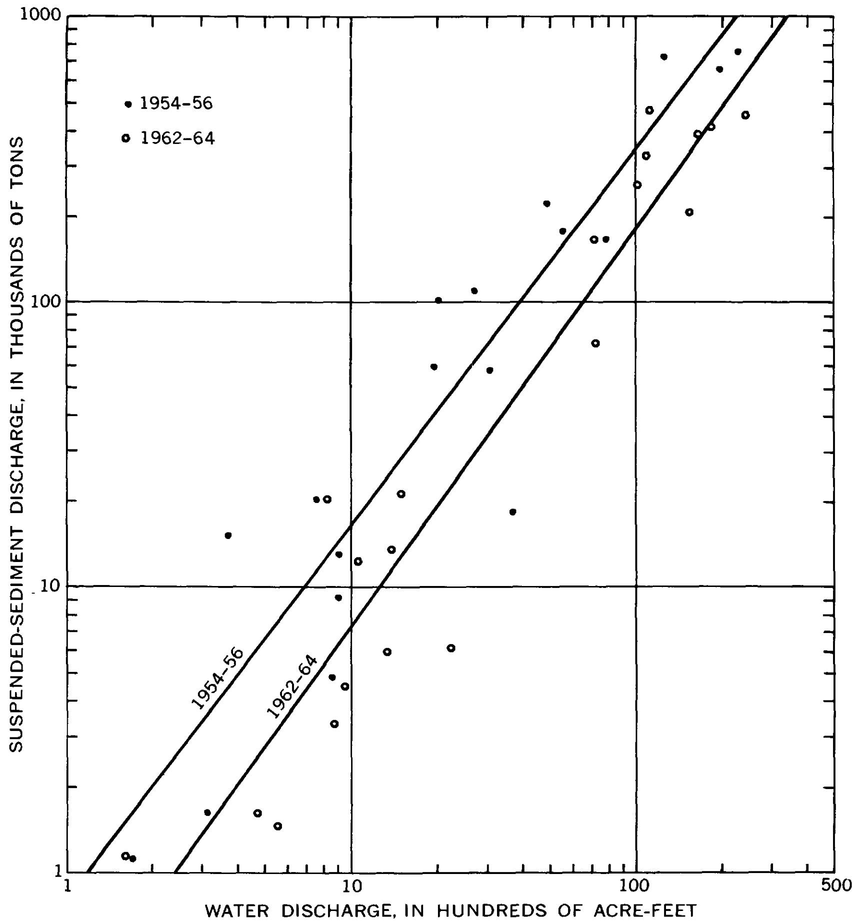

FIGURE 14. — Relation between monthly sediment load and monthly runoff at Willow Creek gaging station for tne periods 1954–56 and 1962–64.

Some observers may feel that the loss of reservoir capacity in Willow Creek basin occurs at a much higher rate than that indicated above. Many reservoirs are filled with sediment to the elevation of the outlet pipe within a few years after construction. It must be remembered that there is a wide variation in sedimentation rates throughout the basin, as indicated by the measured yields. The high-sediment-yield areas receive the most attention, and this tends to leave the impression that sedimentation rates throughout the entire basin are similar. But there are other reservoirs in which capacity-loss rates are very low, and these reduce the average capacity-loss rate for the whole basin. Also, reservoirs — because of their shape — initially lose depth very rapidly. Thus, the reservoirs in the basin appear to be filling very rapidly, especially those in high-sediment-yield areas, lending support to the impression that the sedimentation rate for the entire basin is much higher than it actually is.

SUMMARY

Runoff and sediment-yield data from Willow Creek basin, for the period 1954–68, are presented for use in future structure design and management planning. The effects of conservation structures on both runoff and sediment yields were evaluated on the basis of available data. Frequency curves for the area were developed for 1-day- and 3-day-duration storms, annual precipitation, maximum 3-day-runoff volume, 6-month-runoff volume, and peak runoff rates.

Annual precipitation during the 14-year period 1954–67 varied from 7.01 to 17.37 inches and averaged 11.94 inches, which is slightly less than the 30-year average (12.39 in.). Although the runoff records for three reservoirs vary in length, they run concurrently for the 10-year period 1958–67. For that 10-year period, the following average annual values, in acre-feet per square mile, were recorded: Burnett, 93.9; Cactus Flat, 96.5; and Sheepshed, 37.5. The amount recorded at Sheepshed reservoir is suspect because of an instrumentation deficiency. About 34 percent of the runoff in the gaged basins occurred as the result of snowmelt, and about 66 percent occurred in response to summer rainstorms. About one-third of each year's runoff was produced by a single storm.

Sediment yield varies greatly in Willow Creek basin. Measured yields ranged from 0.09 to 2.00 acre-feet per square mile. The apparent relation between sediment yield of an area and the vegetation which the area supports was used to estimate the sediment yield of the entire basin. Although the evidence is not conclusive, it is believed that realistic estimates of sediment yield within the basin can be made on the basis of vegetative type. Additional data are needed to verify this method.

Conservation structures in the basin are apparently very effective in reducing peak discharge. Best estimates indicate the peak discharge of the 1962 flood at the gaging station was about 45 percent less than it would have been without these structures. Reservoirs and waterspreading systems constructed since 1962 may have increased this percentage considerably. A reduction in annual runoff volume of about 18 percent is indicated, but it is not known how much of this was due directly to structures and how much was due to normal transmission losses. Suspended-sediment concentrations at the gaging station were reduced about 55 percent during an 11-year period. Reservoir storage in the Willow Creek basin is being reduced by 1.6 percent annually.

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